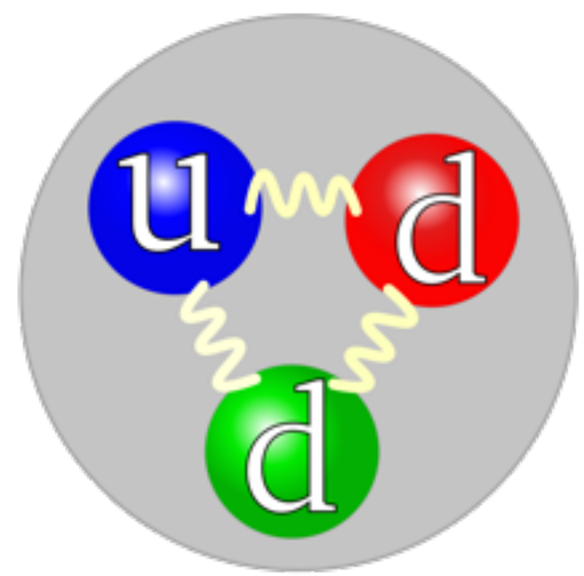
ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

RAIN 15

The neutron metrology laboratory of ENEA INMRI: measurement services and research activities

Lina Quintieri



RAIN15—**RA**diazione per l'**IN**novazione 20**15**

Frascati, 12-13 October 2015

Overview

- **Short Introduction on Neutron Metrology: what is and why is it needed?**

- **Description of the Enea-INMRI Metrology Institute for ionisation radiations**

- **Neutron Metrology Laboratory main activities since 2013**:

    1. Calibration measurement service

    2. Revaluation of primary standards for future intercomparisons

    3. MC calculations for accurate prediction of neutron dose delivered by neutrons in several experiments (external collaborations, european projects, etc)

Neutron metrology: what is and why is it needed?

→ **What is metrology?**

http://www.bipm.org/

Metrology is the science of measurement,
embracing both experimental and theoretical determinations
at any level of uncertainty
in any field of science and technology.

Neutron metrology is the science which enables measurements of the intensity of neutron fields over a wide energy and intensity ranges, with definition and realisation of the physics units for counting free neutrons

The primary physical quantities for which standards are required:

neutron emission rate: number of neutrons emitted from a source

neutron fluence (rate): number of neutrons crossing a defined area (per unit time)

This apparently simple task is made complicated by the very large range of energies and neutron intensities (fluence rates or fluxes) over which measurements have to be made to provide the standards needed by the various end-users.

This enormous range sets a challenge for designing measuring devices and a parallel challenge of developing measurement standards for characterizing these devices.

Calculations are used in neutron metrology to extend and augment measurements. The ability to model devices in detail and to simulate neutron histories accurately has been one of the main sources of improvements in neutron standards over recent years.

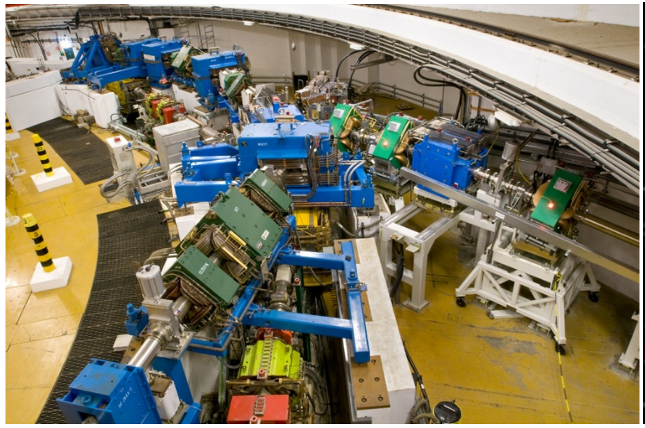
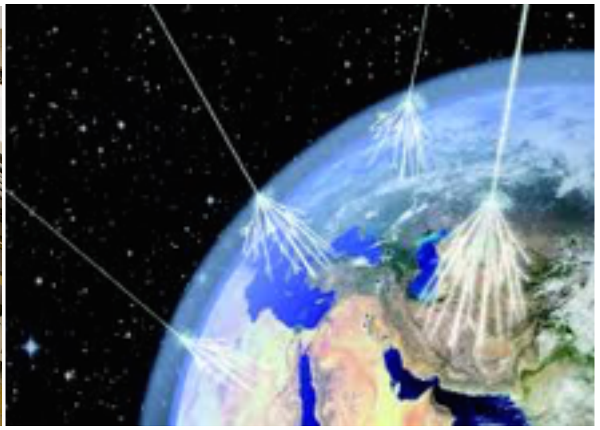
Neutron radiation fields for which neutron metrology is relevant

- Nuclear industry, from the initial fuel enrichment and fabrication processes right through to storage or reprocessing
- High energy accelerators, including photon linear accelerators used for cancer therapy
- Cosmic ray: roughly 50% of doses experienced by fliers at the flight altitudes of commercial aircraft are due to neutrons.
- Research on fusion with a whole new range of challenges because of the very high fluences expected

Provide input parameters for reactor design and control (Criticality dosimetry , etc)

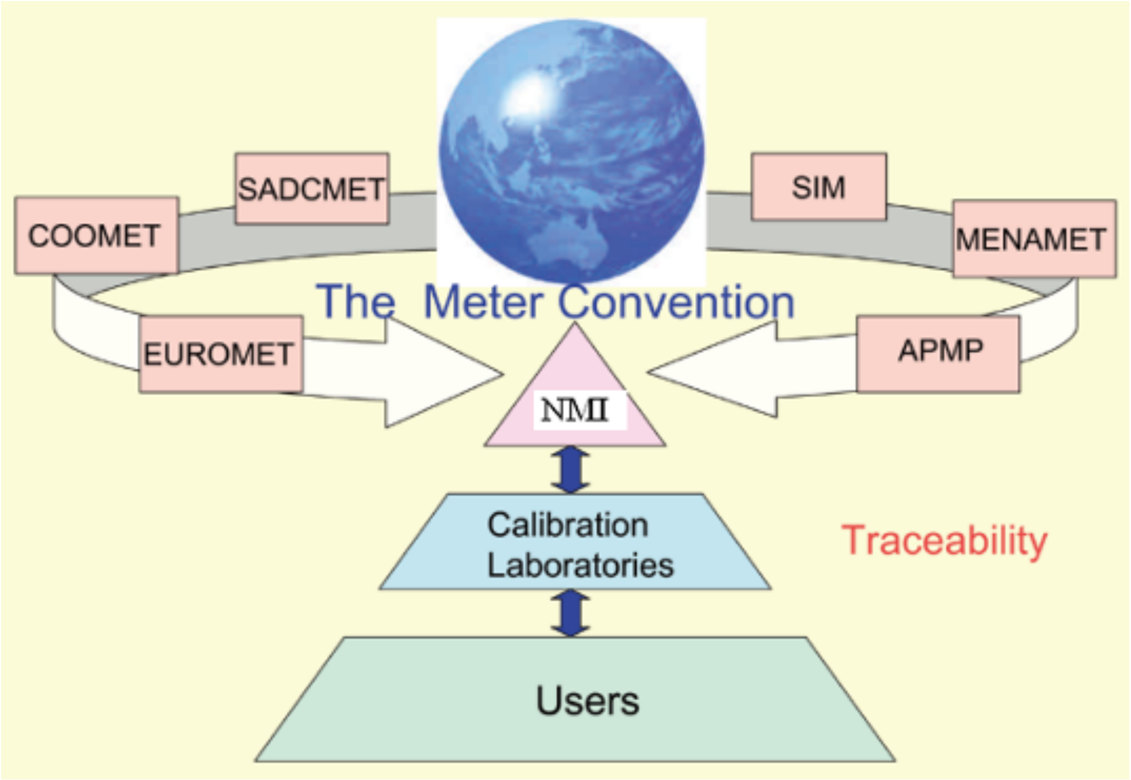
Radiation protection



National Metrology Institutes and BIPM

- Each State has its own metrology infrastructure. In most cases the BIPM interacts principally with one National Metrology Institute (NMI) per State, as nominated through the State's Foreign Affairs Department. **That NMI is responsible for coordinating with any other institutes (NMIs or others) that make up that nation's metrology system**
- The ENEA-INMRI cooperates at the international level under the auspices of the **Bureau International des Poids et Measures (BIPM)** which coordinates the research activities of the NMIs in the words by ensuring world-wide uniformity of measurements and their traceability to the International System of Units (SI).



The BIPM coordinate the NMIs with the authority of the "**Meter Convention"** , a diplomatic treaty between 55 nations, and **it operates through a series of Consultative Committees, whose members are the NMIs of the signatory States.**

The Consultative Committee for Ionizing Radiation (CCRI) has three sections: Section (I) deals with radiation dosimetry, Section (II) with radionuclide metrology **and Section (III) with neutron metrology.**

National Metrology Institutes (NMIs) members of "Neutron Measurement" international commette CCRI(III)

CCRI(III) identifies: 1)areas of neutron metrology that require further attention in the pursuit of improved standards, 2) key comparison reference values and degrees of equivalence.

Members	
President of the CCRI	Dr Wynand Louw
Chairman of CCRI(III)	Dr David Thomas
CMI	Dr Pavel Klenovsky
IRMM	Dr Elke Anklam
KRISS	Dr Dae-Im Kang
LNE	Dr Jean-Luc Laurent Dr Maguelonne Chambon
LNMRI/IRD	Dr Eliana Amaral Dr Carlos José da Silva
NIM	Dr Xiang Fang Mrs Wei Gao
NIST	Dr Willie E. May
NMIJ/AIST	Dr Hideyuki Kato
NPL	Dr Brian B. Bowsher
PTB	Prof. Joachim Ullrich
VNIIM	Dr. Nikolay I. Khanov
Observers	
CIAE	Dr Zhixiang Zhao
CIEMAT	Prof. Cayetano López
ENEA-INMRI	Dr Pierino De Felice
NRC	Dr Alan Steele
IAEA Deputy DG Nucl. Sc. Dosimetry	Mr Aldo Malavasi Dr Ahmed Meghzifene
ICRU Chairman	Dr Hans-Georg Menzel
Guests	
AFRIMETS Chair TC-IR	Mr. Mourad Ben-Hassine Ms. Zakithi Msimang
APMP Chair TCRI	Dr. Peter Fisk Dr. Chul-Young Yi
COOMET President TC IR	Prof. Vladimir KRUTIKOV Prof. Dr. Vladimir Yarina
EURAMET Chairperson TC-IR Chair	Dr. Kamal Hossain Dr Lena Johansson
SIM President MWG6 Ionizing rad.	Mr. José Dajes Dr Lisa Karam
ICRP Scientific Secretary	Dr Christopher Clement
IOMP	Dr K Y Cheung
IRPA President	Renate Czarwinski
iThemba LABS Director	Dr Kobus Lawrie Rudolf Nchodu
ITER Director Head Diagnostics lab.	Dr Osamu Motojima Dr Michael Walsh
SCK/CEN Director	Eric Van Walle Filip Vanhavere

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ENEA-INMRI: the Italian Institute of Metrology of ionisation radiations

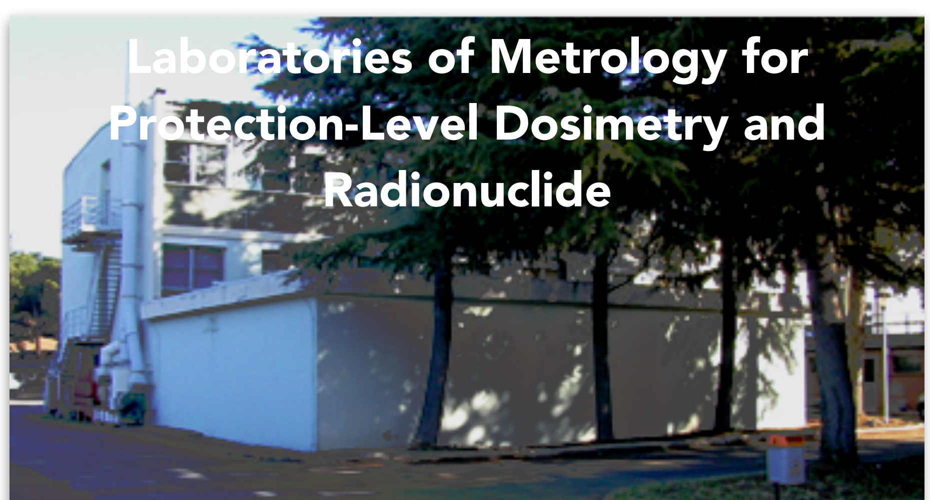
- The National Institute of Ionizing Radiation Metrology "ENEA-INMRI" is responsible for developing and providing the Italian national standards relating to the ionizing radiation quantities.
- ENEA-INMRI belongs to ENEA and is located at the ENEA Casaccia Research Centre, near Rome.
- The ENEA-INMRI calibration and measurement capabilities (CMCs) are internationally recognised in the frame of the MRA (as described in the BIPM Web site)
- **The metrological activities at ENEA-INMRI include the development and maintenance of Italian national standards in the field of ionizing radiation and are carried out along the following lines:**

  Therapy level and industrial radiation processing dosimetry standards

  Protection level dosimetry standards

  Radionuclide standards

  Neutron standards.



ENEA-INMRI main activities

1.Development and maintenance of primary and secondary standards

- Inter-comparison with other NIMs
- Participation to international commettes and organism (BIPM, CIPM, CGPM, EURAMET)

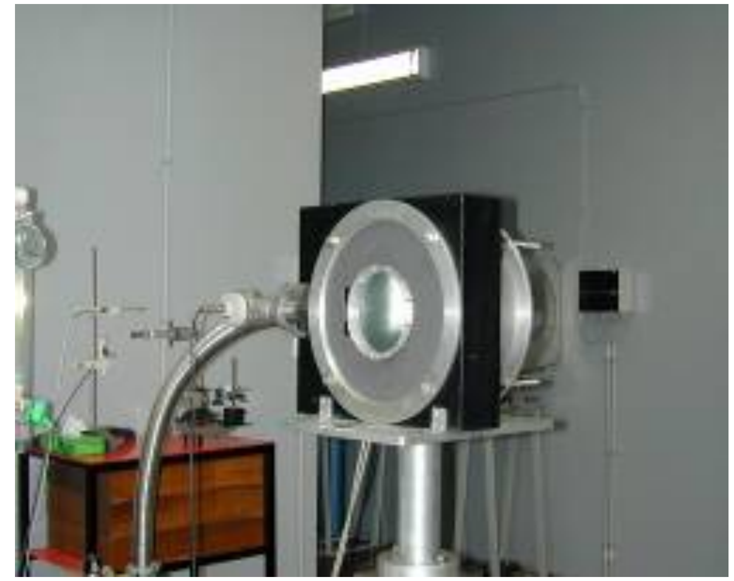
2.Research on measurement methods and standardisation of measurement procedures

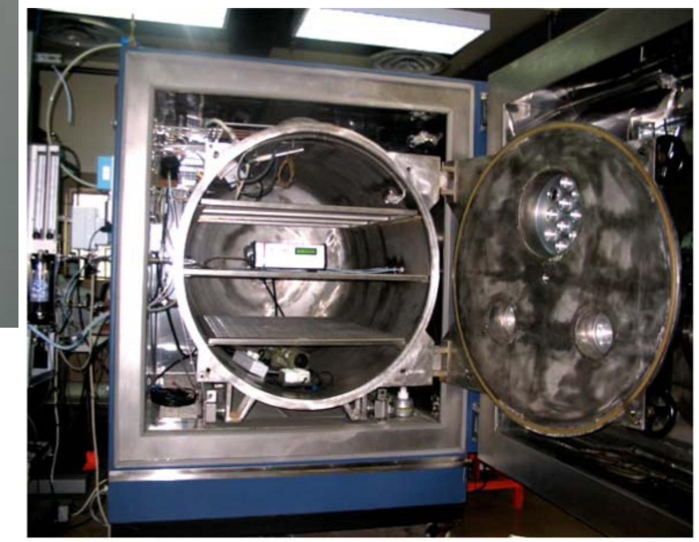
- National inter-comparisons

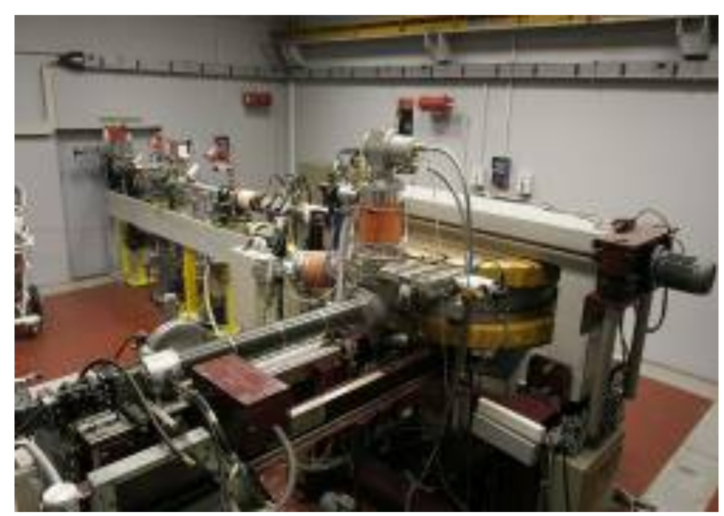
3.Certification and Accreditation

- Calibration service and certification
- Accreditation of secondary standard laboratories (ACCREDIA LAT centres)

4.Didactics and Academic Activities







ENEA neutron metrology main activities

- **Providing source based calibration fields and measuring neutron source emission rates**
- Characterisation of neutron calibration fields at external facilities (in this frame there is an ongoing collaboration with TRIGA Ing. A. Grossi)
- Participation in international comparisons (as scheduled in 2015 CCRI(III) meeting)
- Monte Carlo simulation for experiments (also in the frame of scientific collaborations with other European Nuclear Research Institutes)
- Irradiations and calibrations of detectors and dosemeters in (quasi-) monoenergetic neutron fields (thermal) and in neutron fields with broad energy distributions (AmBe, AmB, PuBe, Cf)
- Neutron Training courses of "Suola di Specializzazione in Fisica Medica" for University of Tor Vergata (Rome)

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- **Providin ... e emission rates**
- **Charact ... his frame we recall ... A Ing. A. Grossi)**
- **Particip ... II) meeting)**
- Monte C ... borations with othe
- Irradiatio ... nergetic neutron f ... s (AmBe, AmB, PuE
- Neutron ... dica" for University

From last CCRI(III) meeting

New Comparison

Neutron source emission rate (new K9)
Source = ^{252}Cf (Cm to be studied but problem of energy distribution)

Pilot = NPL (Neil Roberts) – to be confirmed due to source availability

Participants: ENEA, NRC, KRISS, NIST, LNHB, CMI, NPL, NIM, VNIIM, NMIJ (+LNMRI?)

H*(10): starting 2016
Circulation of two « Smartrem » survey meter: one PTB and one IRSN
Comparison of H*(10)/count or of calibration factor

Field (1 or several among the following):
AmBe, Cf, Cf+D2O (30 cm)

Pilot : PTB (Andreas Zimbal) – stability check at PTB between participants

Participants: NMISA, NPL, CMI, KRISS, NIST, NMIJ, PTB, NRC, ENEA, VNIIM, IRSN, SCK/CEN, CIEMAT, NIM, others? (LNMRI, ARPANSA, SMU)

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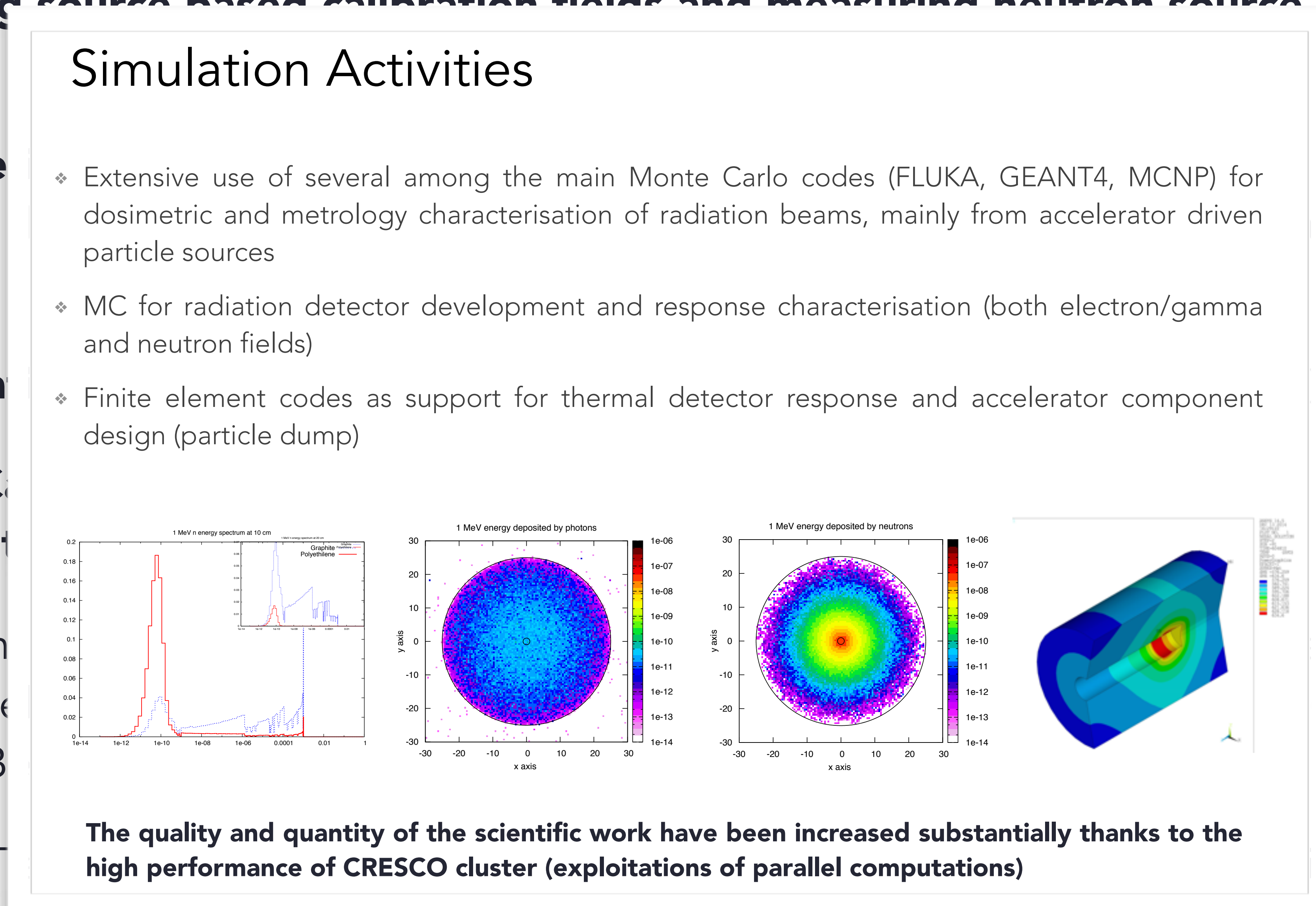
- Neutron T... a" for University of Tor Vergata (Rome)



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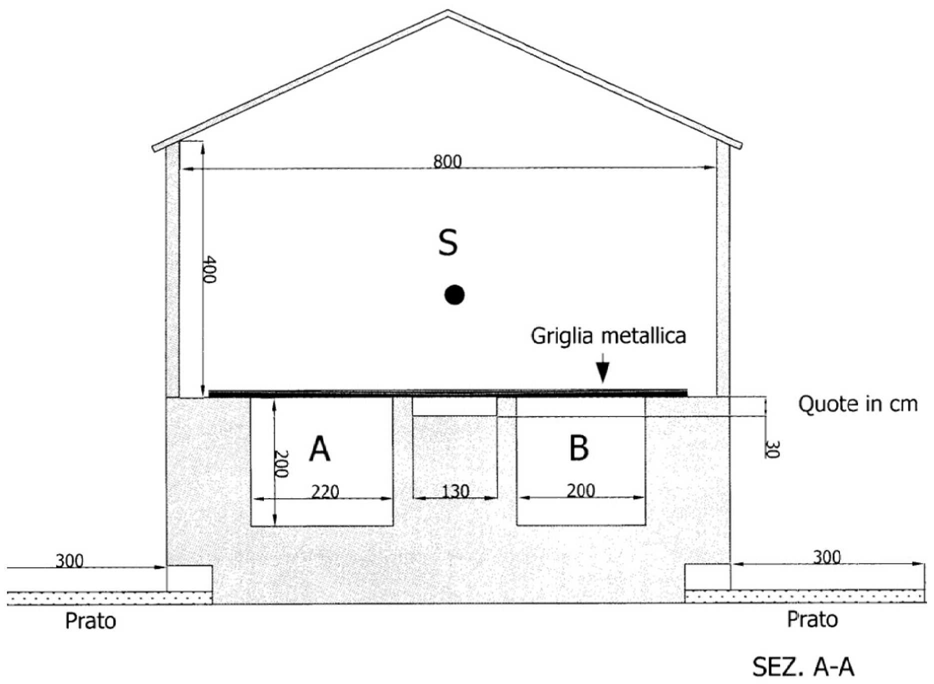
- **Neutron Training courses of "Suola di Specializzazione in Fisica Medica" for University of Tor Vergata (Rome)**

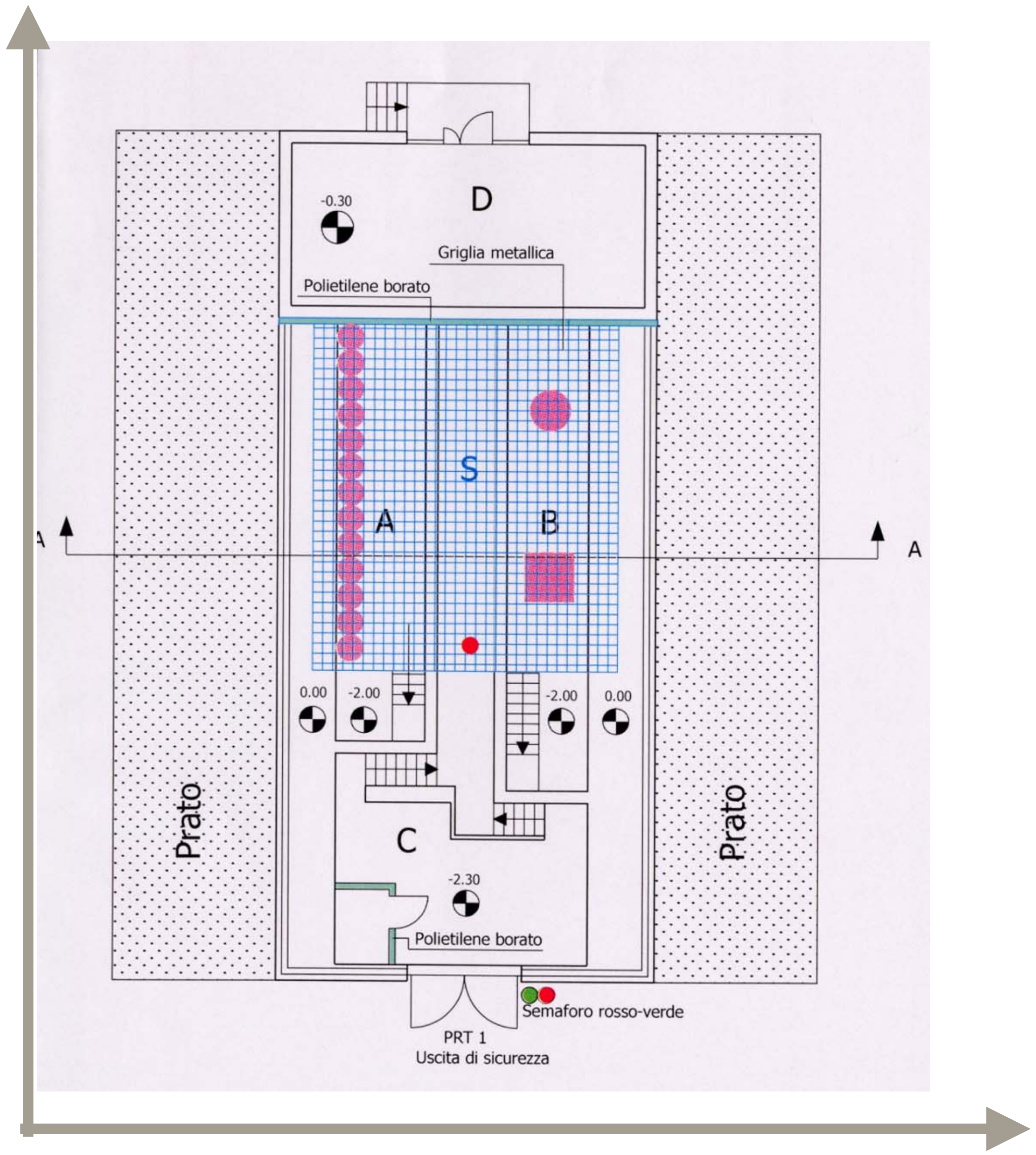
“The facility”

Laboratory layout

A is the neutron source storage room
B is the primary standard room (neutron thermal flux and $MnSO_4$ bath sphere)
S is the calibration room

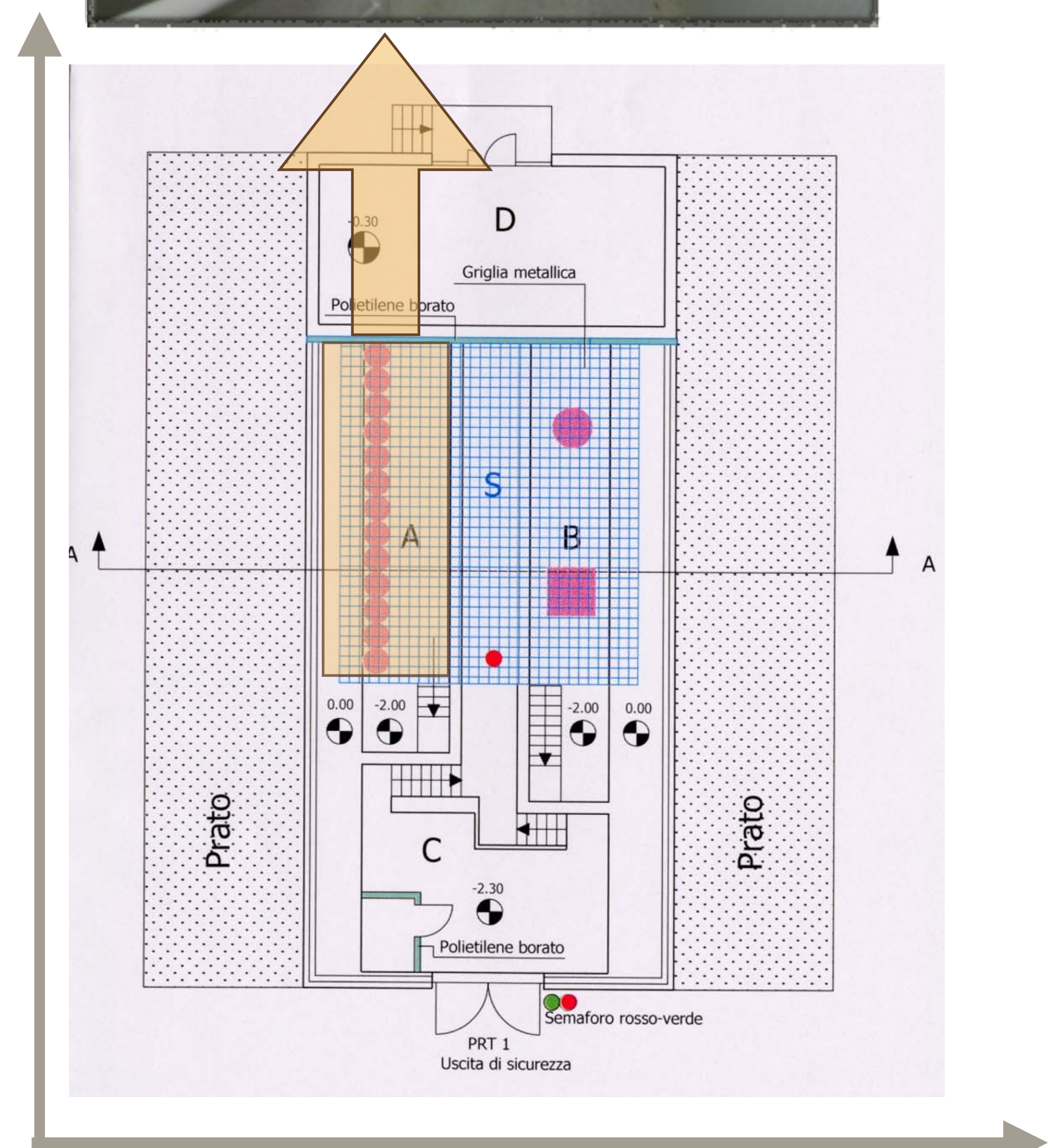
Room	W (m)	H (m)	L (m)
A	10	2	2
B	11.5	2	2
C	4	6	6
S	16	8	4





Source storage room

Room	W (m)	H (m)	L (m)
A	10	2	2
B	11.5	2	2
C	4	6	6
S	16	8	4



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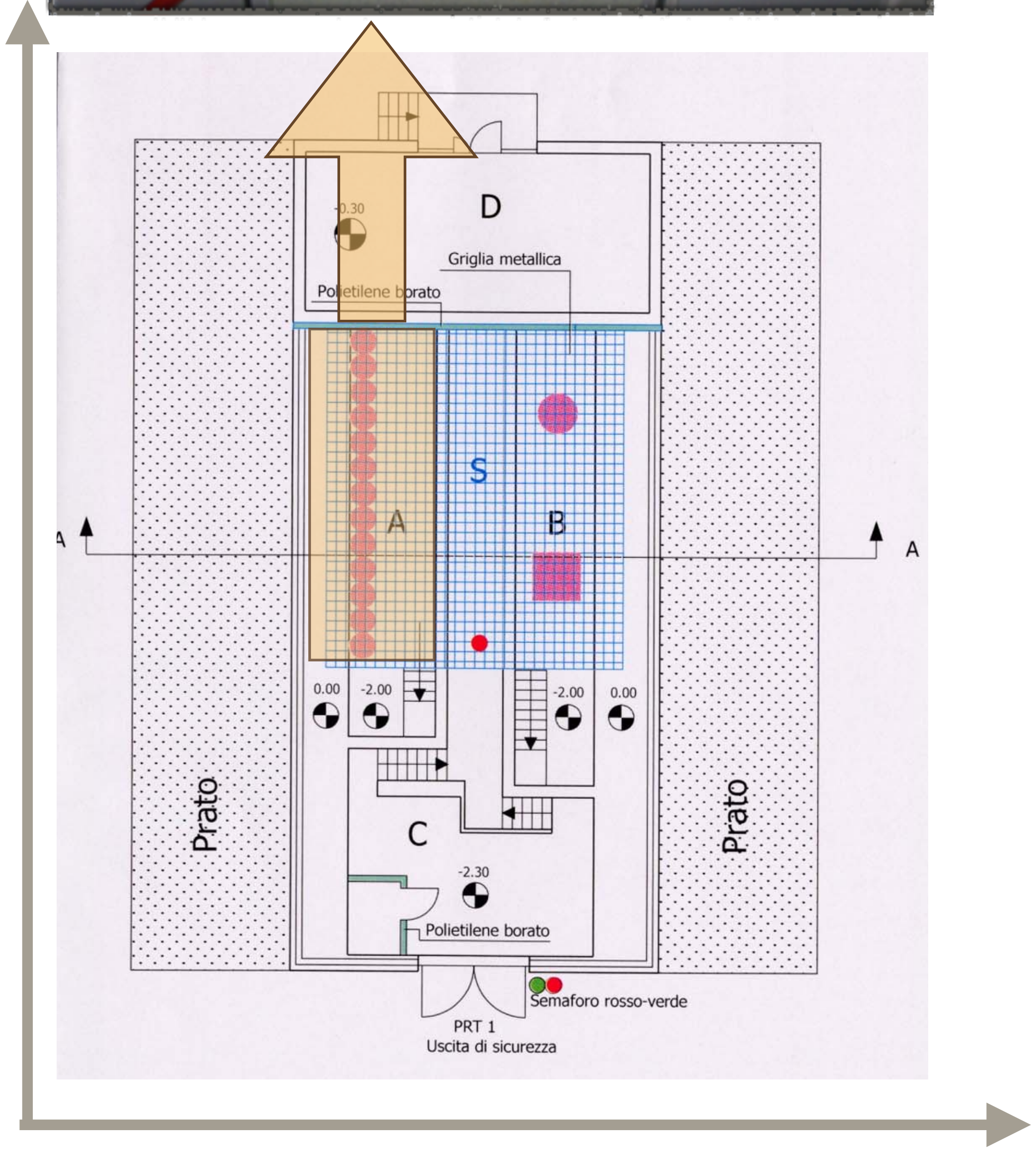
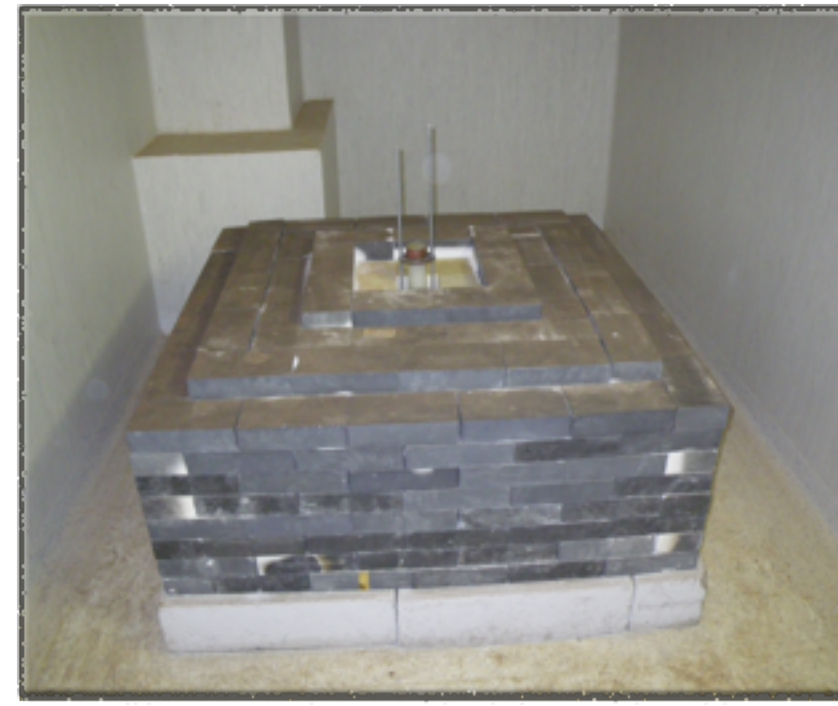
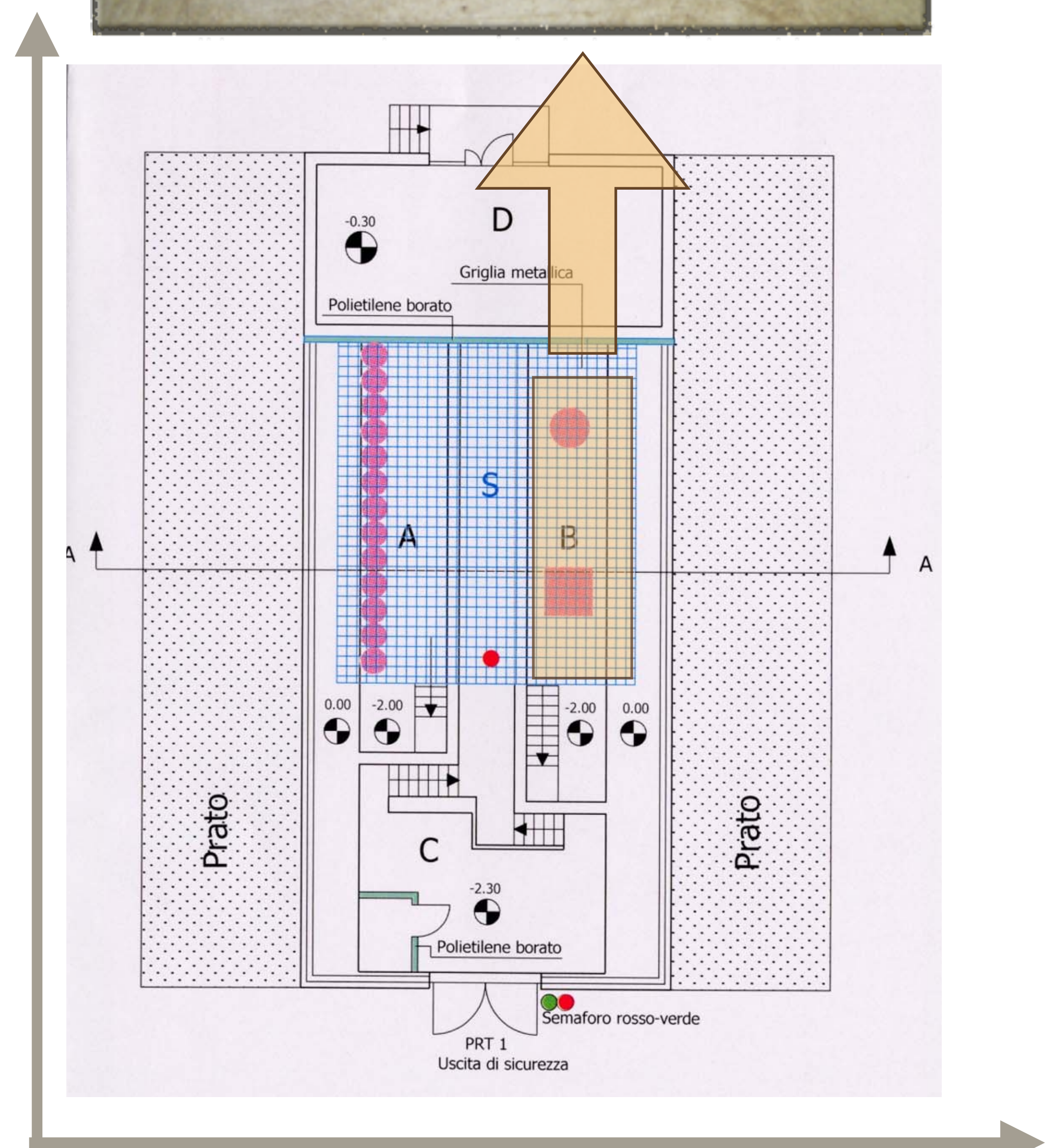


Thermal Standard and MnSO4 bath room

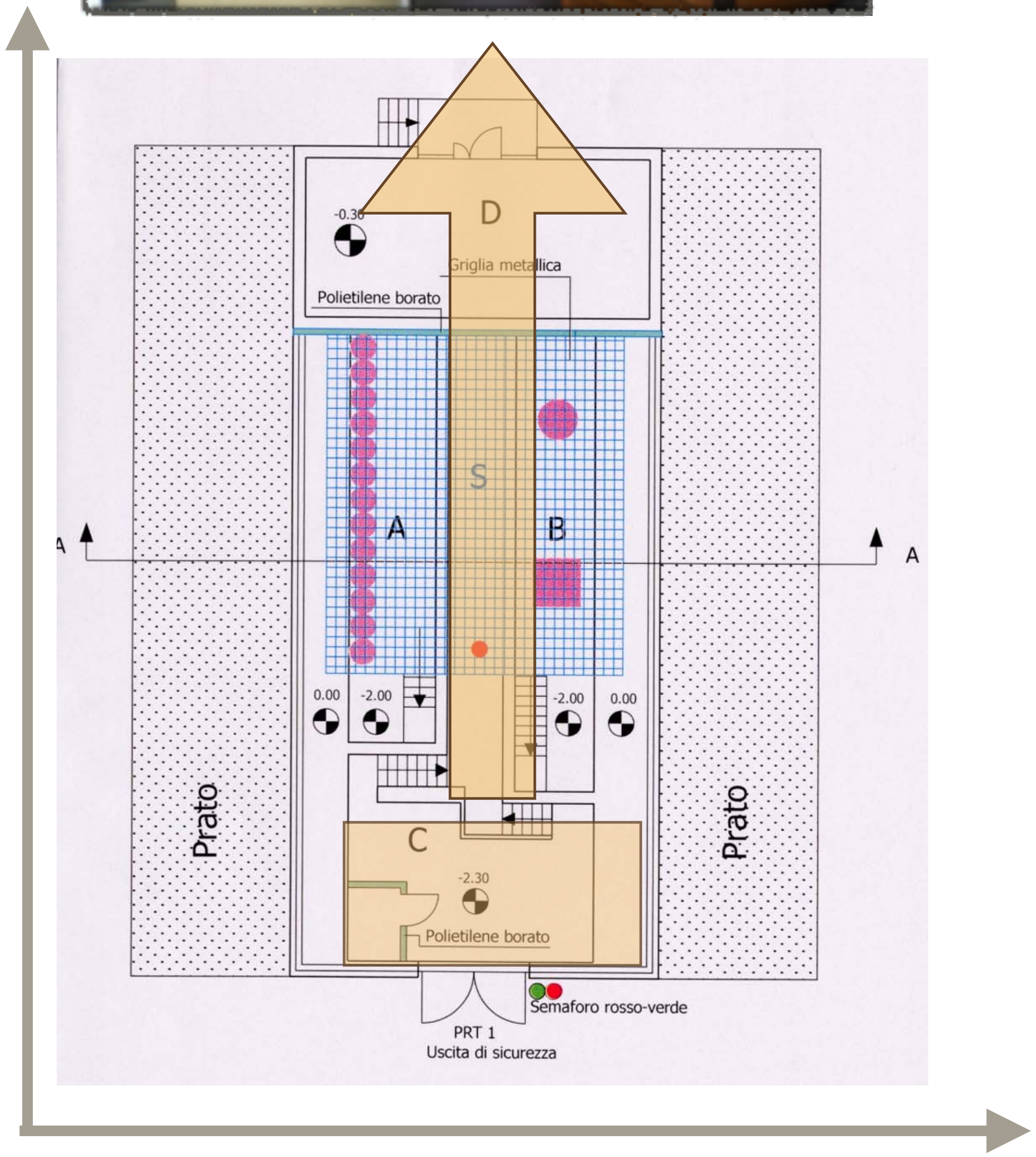
Room	W (m)	H (m)	L (m)
A	10	2	2
B	11.5	2	2
C	4	6	6
S	16	8	4





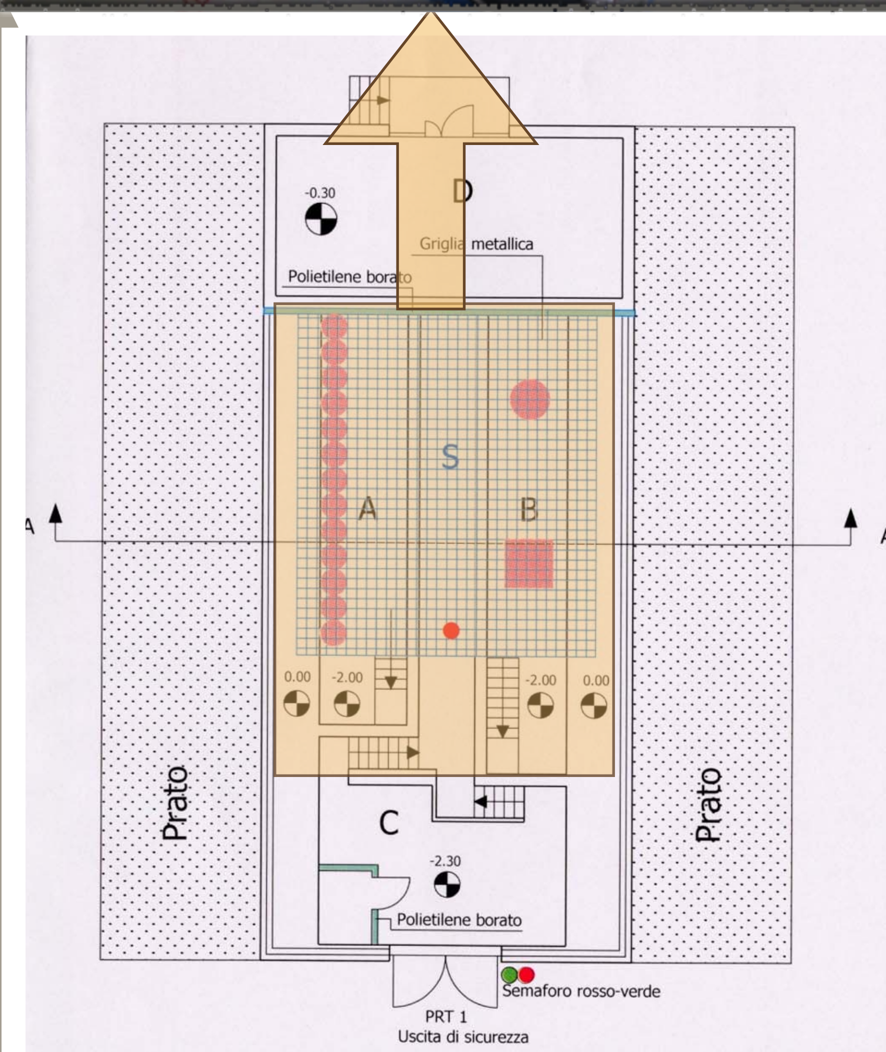
Control room

Room	W (m)	H (m)	L (m)
A	10	2	2
B	11.5	2	2
C	4	6	6
S	16	8	4



Irradiation room

Room	W (m)	H (m)	L (m)
A	10	2	2
B	11.5	2	2
C	4	6	6
S	16	8	4



Total neutron source inventory

For calibration reference fields

Source Type	Quantity	Neutron Emission rate[s^{-1}]
Am-Li	2	1.0 E+05 4.0 E+04
Am-F	1	4.5 E+05
Am-B	1	4.0 E+05
Am-Be	4	**2.2 E+06 (**)** **2.9 E+06 (**)** 2.4 E+06 7.2 E+04
Po-Li	1	1.3 E+01
Cf-252	4	6.9 E+04 2.9 E+03 1.2 E+02 4.6 E+01

AmBe sources embedded in the thermal neutron density standard

Source Type	Quantity	TotalActivity [Bq]
Am-Be	6	2.10E+11

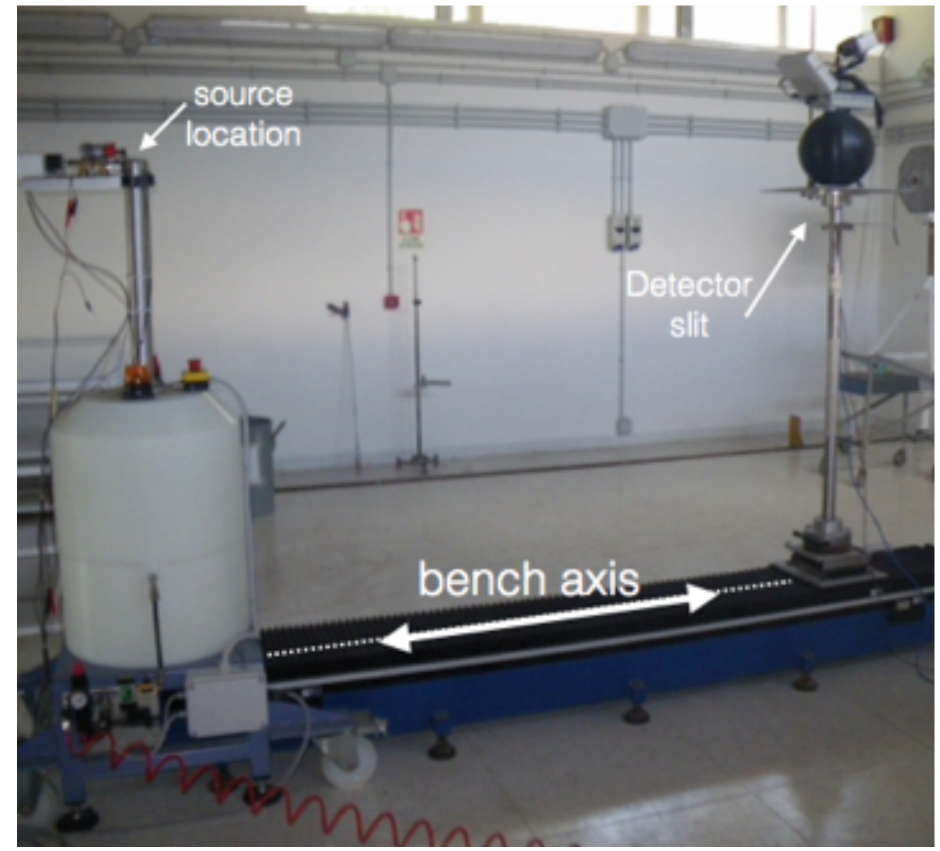
(**) Values measured by $MnSO_4$ bath calibration in 2012.

The Purchase of new Cf-252 sources is planned for the next year.

Calibration Service (1/2)

Neutron device calibrations:

- Since 2013 main focus and effort on maintaining and improving the survey meter calibration service
- Two calibrated AmBe (ISO X3) sources are used to produce reference fields
- Their neutron emission rates have been estimated by the $MnSO_4$ method in 2012 [ref. M. Amendola,et al. Radioanal. Nucl. Chem. 301, 109 (2014)]
- The neutron fluence to ambient dose equivalent conversion is calculated using the AmBe neutron energy spectrum provided by ISO-8259 and the conversion coefficient given in ICRU Report ($h\varphi^*=391$ pSv cm^2)
- The response of the dose rate meter is measured as a function of the distance from the source and corrected by the room scatter correction applied using the ISO "Reduced fit method"



The range of ambient equivalent dose rate for calibration goes from 8 μSv/h to 350 μSv/h (it is going to be extended by acquiring a 5 times more intense PuBe source)

Experimental accurate measurement of the reference neutron spectrum has been planned and it will be carried out in collaboration with LNF-INFN (G.Giordano, M. Iannarelli)

Certification Service (2/2)

page n. 1 of 6, 73/N

Istituto Nazionale di Metrologia
delle Radiazioni Ionizzanti

CALIBRATION CERTIFICATE

N. 73/N

This Cerificate is consistent with the calibration and measurement capability (CMC) specified in Annex C of the "Mutual Recognition Arrangement" (MRA), drawn up by the International Commettee of Weights and Measures (CIPM) under the authority assigned by the Metre Convention. In the framework of MRA, all participating national metrology institutes recognize each other the validity of the calibration measurement certificates, issued for quantities, ranges and measurement uncertainties listed in Annex C (for further details, consult the official Bureau International des Poids et Mesures (BIPM) website: http://www.bipm.org).

Table I-Instrument and experimental measurement set-up

Customer	Advanced Accelerator Applications- Colleretto Giacosa Ivrea (To) ITALY
Instrument Specifications	
Manufacturer	Berthold Technologies
Detector type Model Monitor model Serial number Internal Calibration Factor	Neutron probe- rem counter LB 6411 LB 123 6347 1.207
Measurement Parameters	
Measurement period	From 11 to 12 April 2014
Irradiation direction	Instrument monitor in front of the source and the probe centre aligned to the source centre along the irradiation bench axis (see Annex A)
Source type	^{241}Am-Be(α,n)
Source code	4335
Emission rate @ 11/04/2014	2.196 10^{+6} s^{-1}
Distance range for calibration	15.0 ÷ 181.2 cm
Certificate page number	6 (six)

INMRI Protocol Nr. INMRI/0025/2014

Table II – Calibration Factor

Reading scale on the instrument monitor during measurements *(micro Sv per hour)*	N_Φ	N_H
$H^*(10)$ [μSv/h]	0.6738 [μSv^{-1} h s^{-1} cm^{-2}] *(2.4257 10^{+9} [Sv^{-1} cm^{-2}])*	0.9484

The uncertainties of N_Φ ed N_H factors are reported in Table III.
This certificate consists of 5 pages. All the details concerning the adopted calibration procedure are described from page 2 to page 6.

Calibration performed by
Eng. L.Quintieri

Istituto Nazionale di Metrologia
delle Radiazioni Ionizzanti
the Responsible
(Dott. P. De Felice)

This certificate can be exclusively reproduced faithful to the official version as released by ENEA-INMRI.
Any partial reproduction of the certificate must be authorized by the ENEA-INMRI.

2013-up today survey meter	Quantity
LB6411+UMO123	10
LB6414	1
Thermo	5
Alnor	4
Inspector 1000	3
Atomtex	1
Victoreen	2
Thermo Fisher Ele. Corp.	1
Ludlum Meas. Inc	1

The released certificate complies with the generic prescriptions of **ISO/IEC 17025**

~ 30 dose rate meters have been calibrated since 2013, mainly for hospitals and other Italian research institutes

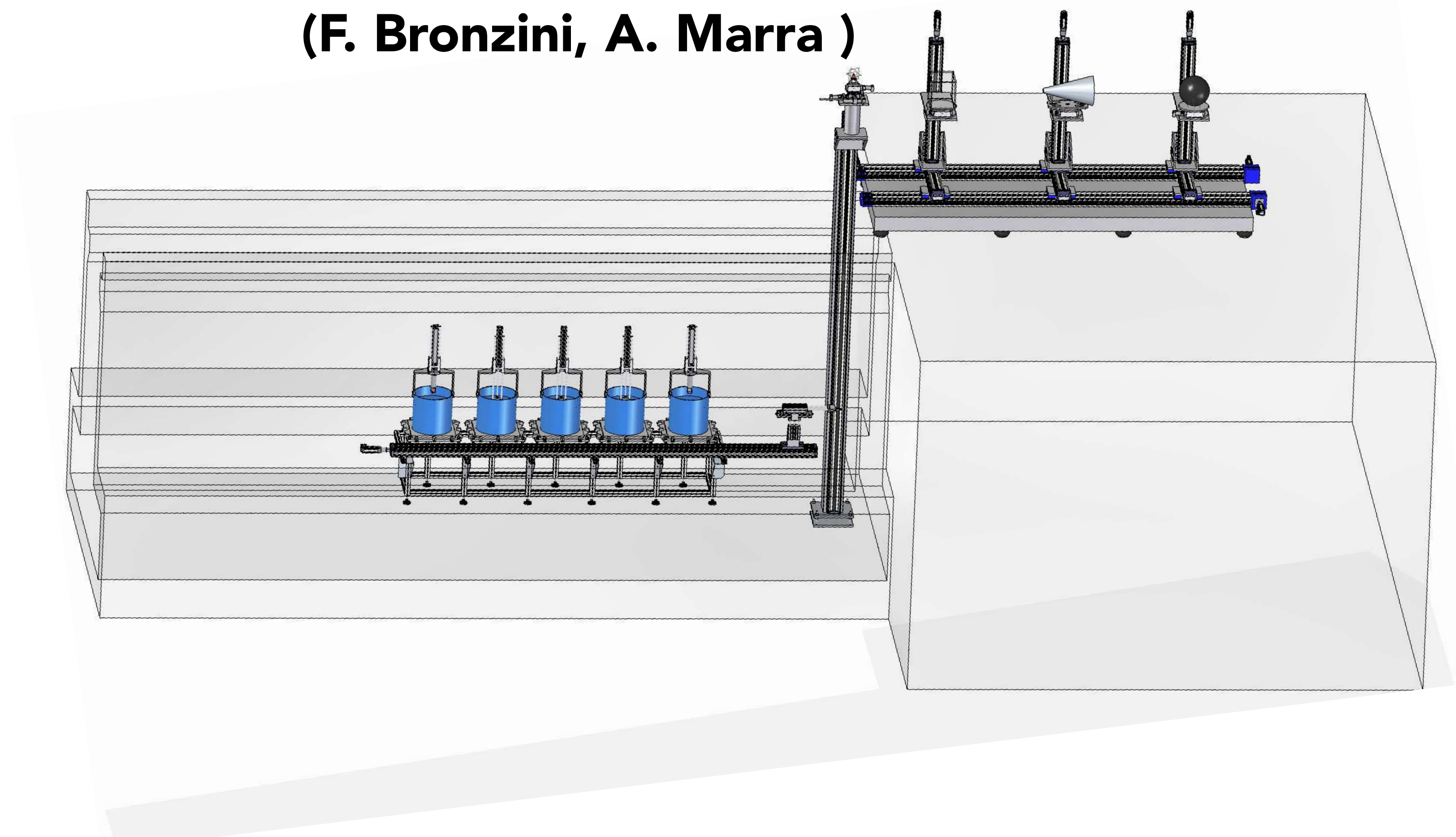
Future plan for the Calibration Service

Improving the measurement procedure using a gamma source (suitable portable Cs-137 source) or, alternatively verifying the photon response of survey meters or neutron detectors using the Cs-137 INMRI-ENEA reference beam.

Measurements of the room scattering radiation contribution, by using ISO shadow cones. This will require to build an aligned and movable support for the cones.

Work is in progress in order to develop electronic acquisition of readout for Berthold and Thermo digital survey meters (digital signal processing)

Preliminary design, courtesy of Tecnicom
(F. Bronzini, A. Marra)



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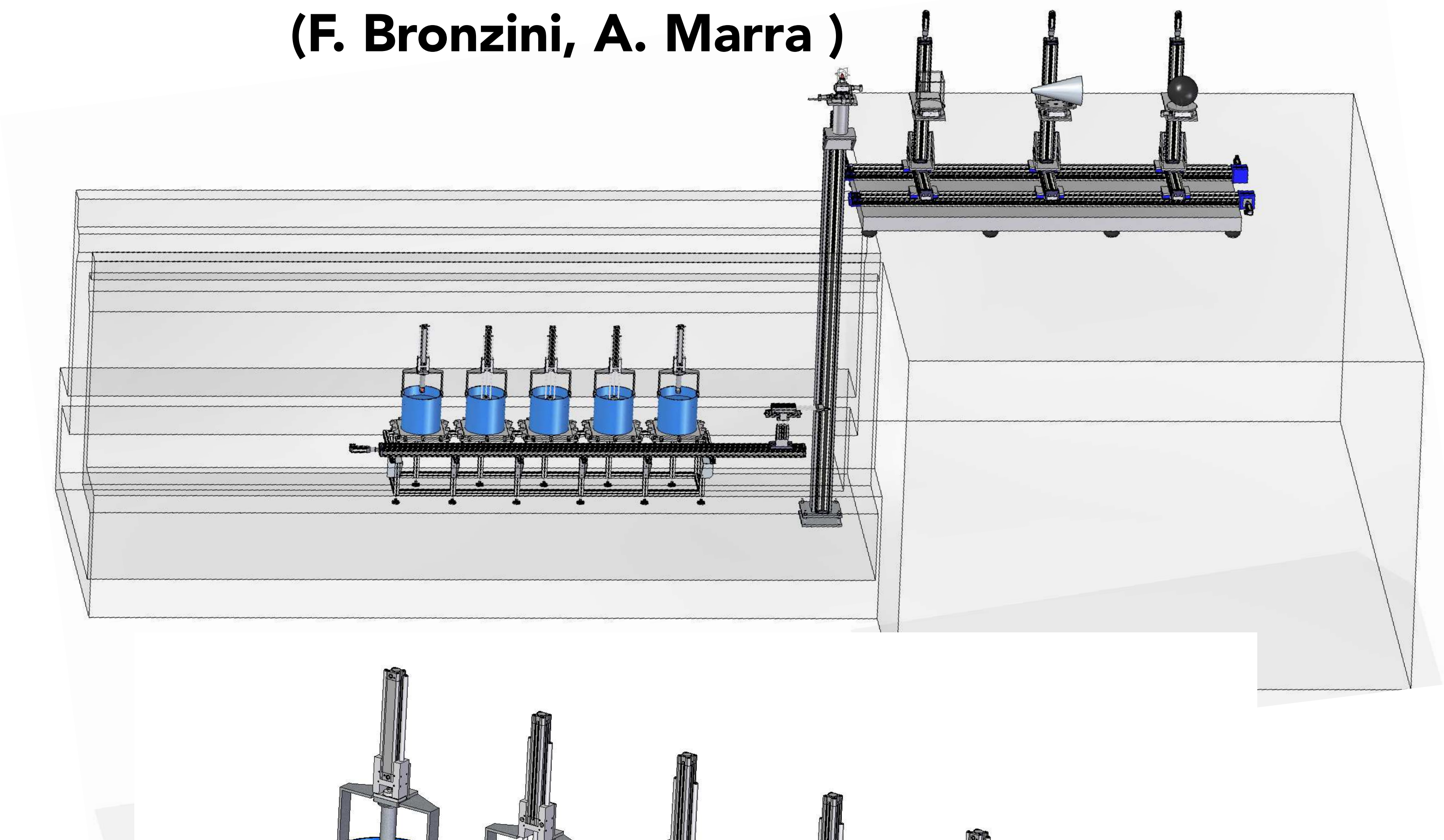
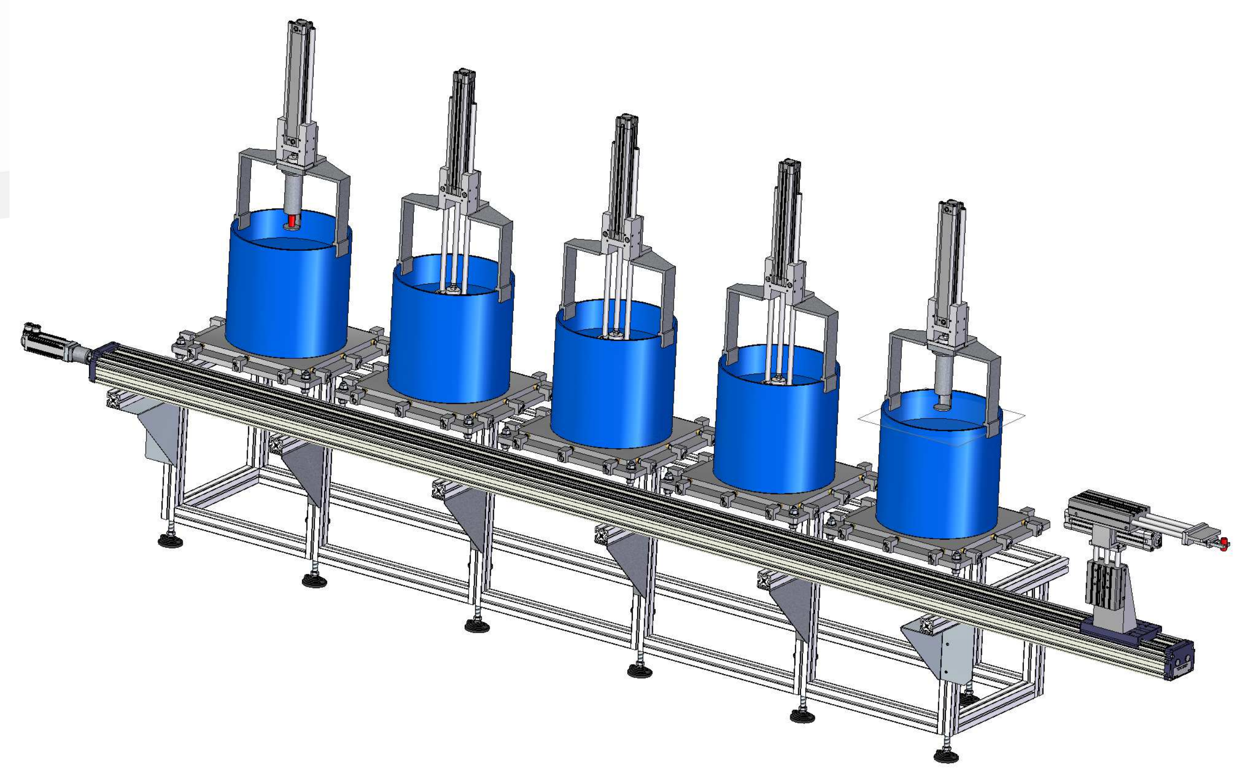




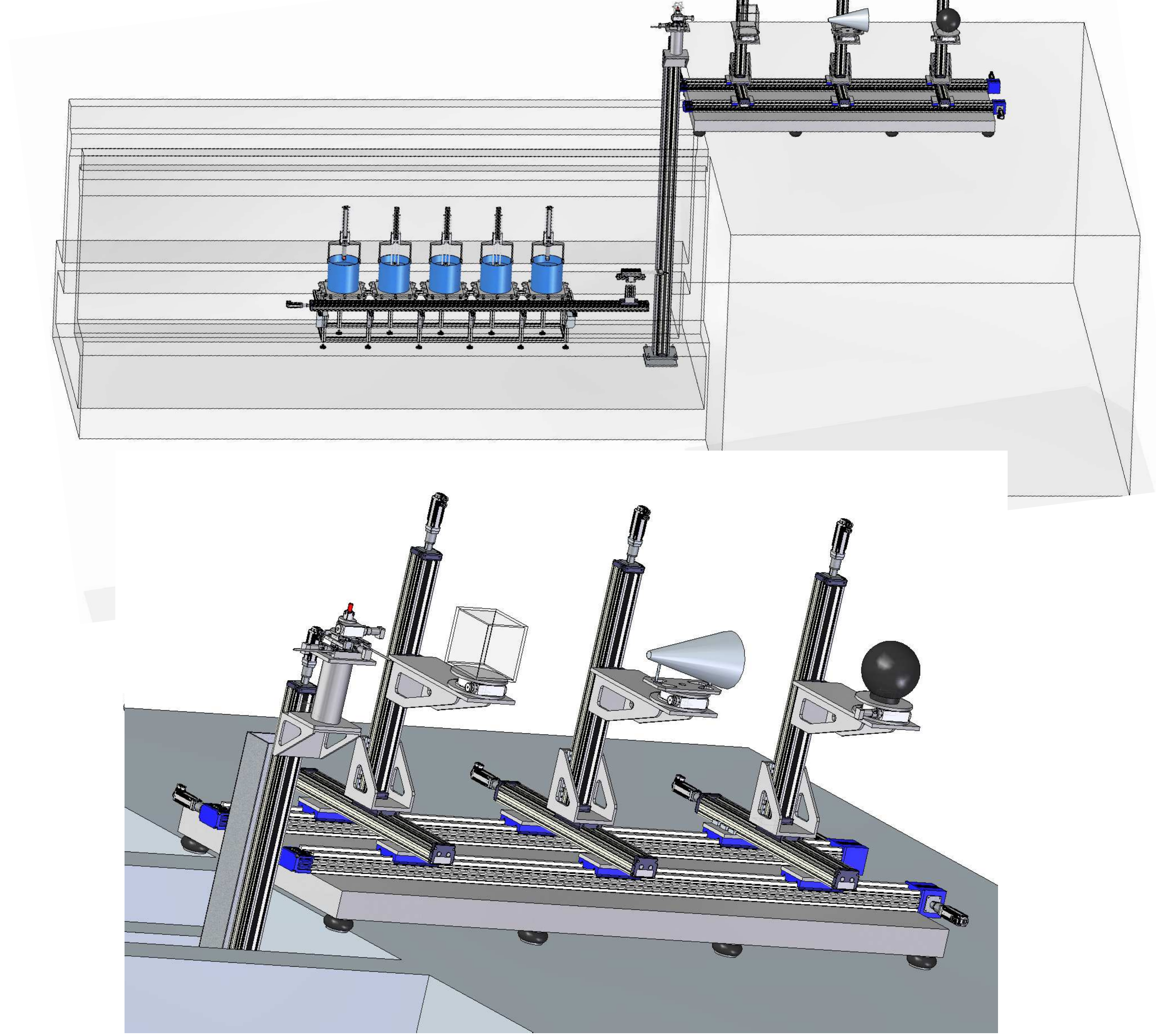
Future plan for the Calibration Service

Improving the measurement procedure using a gamma source (suitable portable Cs-137 source) or, alternatively verifying the photon response of survey meters or neutron detectors using the Cs-137 INMRI-ENEA reference beam.

Measurements of the room scattering radiation contribution, by using ISO shadow cones. This will require to build an aligned and movable support for the cones.

Work is in progress in order to develop electronic acquisition of readout for Berthold and Thermo digital survey meters (digital signal processing)

Preliminary design, courtesy of Tecnicom (F. Bronzini, A. Marra)



“Primary Standards”

Neutron Emission rate

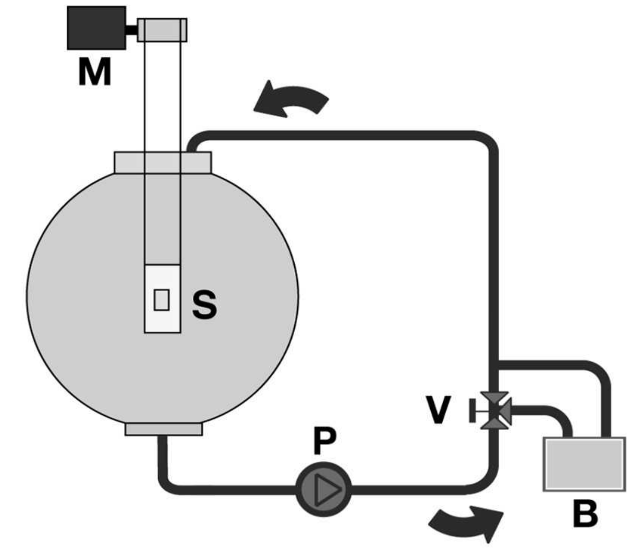
Thermal neutron flux density

National standards maintained at the ENEA-INMRI (Italy) in the field of neutron metrology.

Quantity	Standard	Radiation Quality	Uncertainty*	Measurement range
Neutron emission rate	Manganese sulphate bath (MnSO_4)	^{241}Am-Be	1.5	10^5-10^7 $[s^{-1}]$
Neutron flux density	Thermal neutron flux density standard	Thermal neutrons	1.5	$1.2 \cdot 10^4$ $[cm^{-2}s^{-1}]$

* The uncertainty values are relative (%) combined standard uncertainties (k=1).

Primary standard for the neutron emission rate: The MnSO4 bath



$$^{55}Mn + n \rightarrow (^{56}Mn) \rightarrow ^{56}Fe + \beta + \gamma$$

At the end of 2012 two AmBe sources have been calibrated, using the MnSO4 bath absolute method:

The emission rate values with these sources have been measured with uncertainty of less than of 1.5%:

1) (2.24 ± 0.03) · 10^6s−1

2) (2.89 ± 0.04) · 10^6 s−1

These two sources are presently used to generate the neutron reference field for calibration purposes

The MnSO4 bath is contained in an AISI 306L stainless-steel spherical vessel with 100 cm inner diameter and 5 mm thickness

A 30 cm diameter opening on the top of the steel sphere allows the arrangement and movement of the neutron source inside the bath.

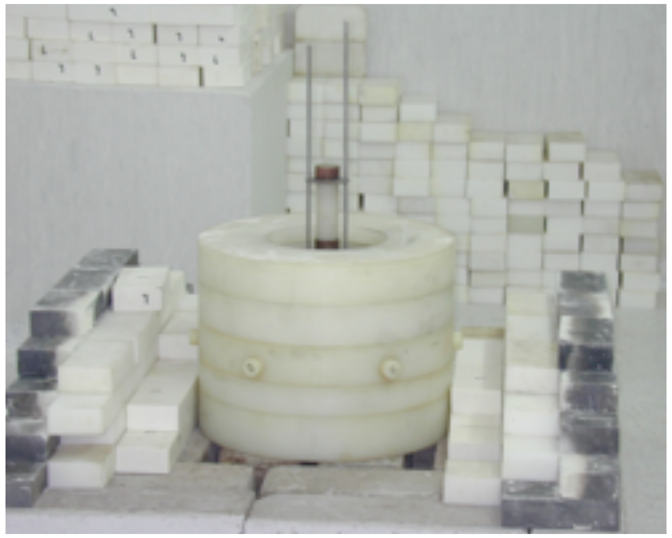
The spherical vessel has a capacity of about 520 l of MnSO4 aqueous solution (used concentration of 1.1152mol/l with density of 1.1564g/cm3).

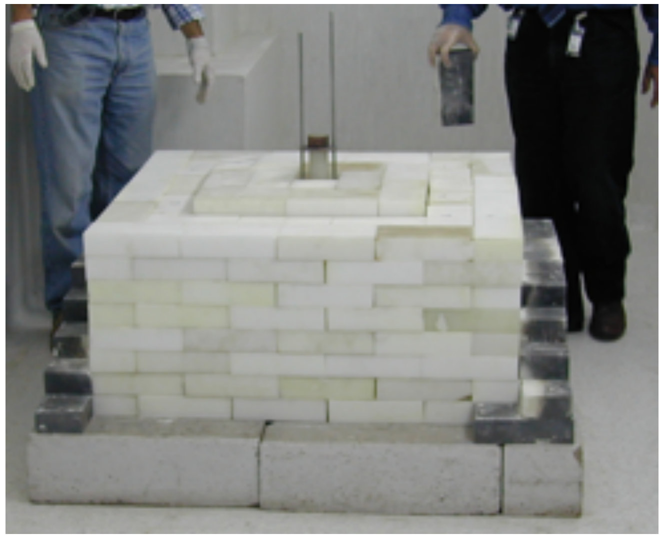
The bath is kept homogeneous thanks to an external pump, with flow rate of 1000 l/h, that circulates the solution trough an external auxiliary circuit.

The rate at which activity is produced is proportional to the neutron emission rate of the source, hence the neutron rate can be found by measuring the decay rate of 56Mn or equivalently counting the gamma ray emitted, using an NaI(Tl) scintillator

Primary standard for thermal neutron flux density

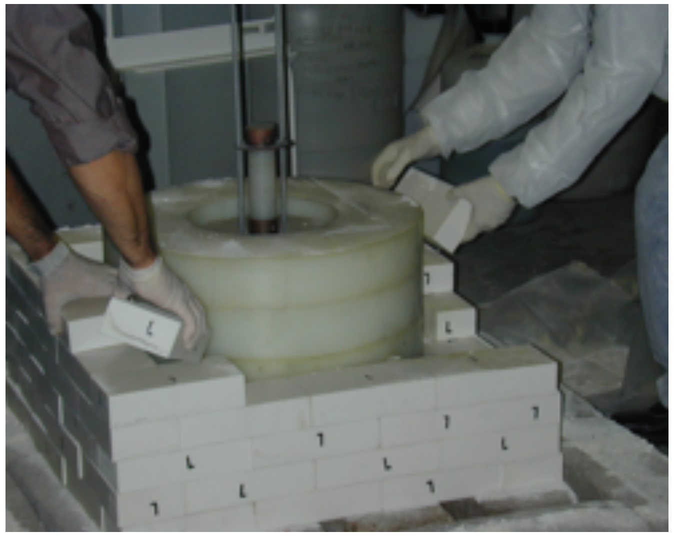
The thermal neutron flux standard was assembled first in 1973. [E. Rotondi, The Thermal neutron flux density standard at C.S.N.: design and calibration, Report CNEN-RT/PROT(73)37 (1973)]

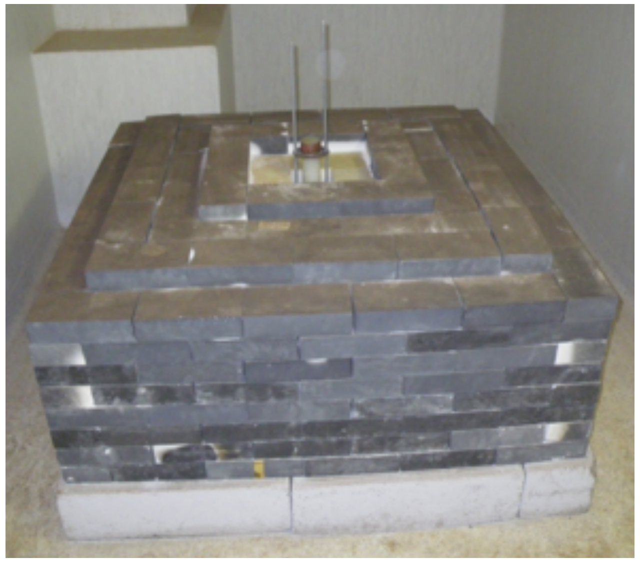




It consists of a reactor grade graphite cylinder (25 cm diameter, 20 cm high), surrounded by a 13.5 cm thick polyethylene reflector, which acts as moderator and shield.

Six Am-Be neutron sources (with an average individual emission rate of about 1.E+6 s^−1) are located in the polyethylene reflector 60 degree apart,





The irradiation cylindrical air cavity has 5cm diameter, 10 cm height. A movable polyethylene-graphite plug closes the access to the irradiation cavity.

The standard was calibrated by the gold foil technique giving a flux density of 1.217·10^4 /cm^2/s with 0.9% uncertainty. The Cadmium ratio R_Cd =9.31+/- 0.05, with a spacial uniformity better than 0.2%

The foil activity measurements are traceable to the national standard of radionuclide activity (Bq). In 2005 the thermal fluence standard was completely dismantled and moved to the present location (ENEA-INMRI Neutron Laboratory).

Study of feasibility of a thermal neutron irradiation system for calibration of personal dosimeters in terms of Hp(10)

Goal: 35 cm diameter cylindrical air cavity (to allow the uniform irradiation of 30cm x30cm x15 cm water slab phantom, according to what stated on Hp(10) by International Standard ISO 8529-3)

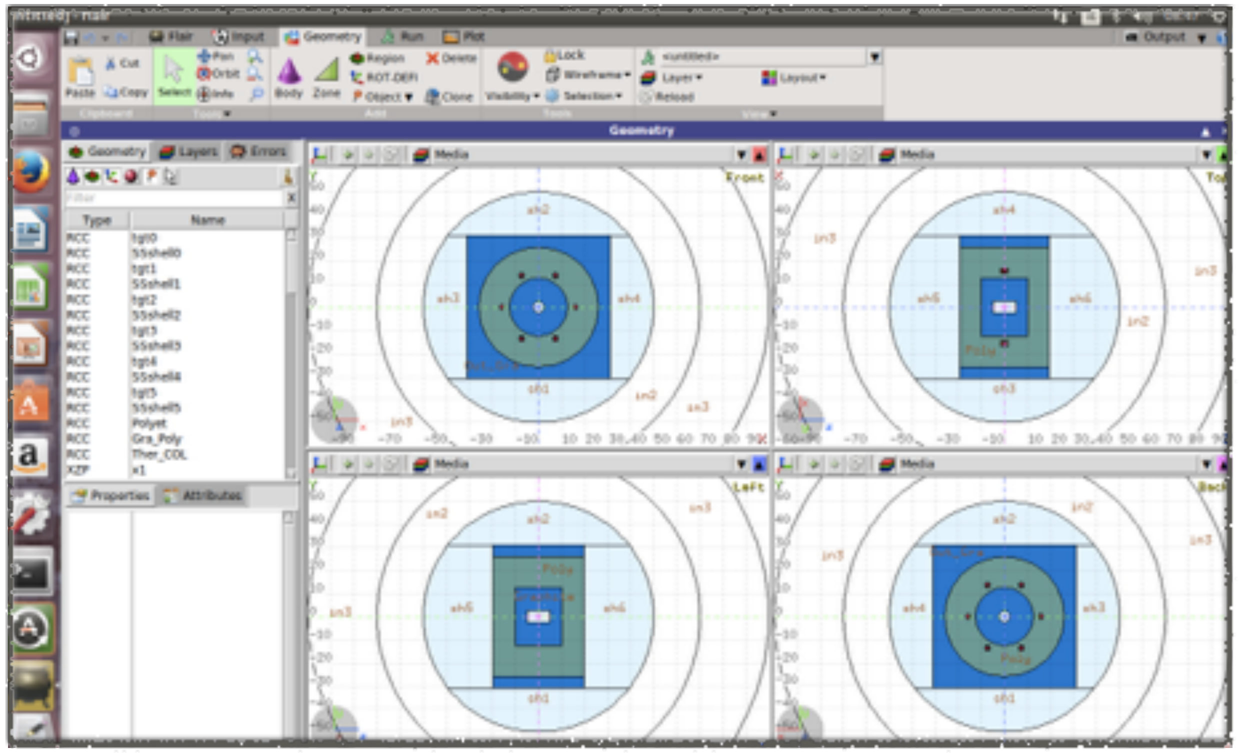
It is foreseen to use AmBe sources to reach in the cavity at least a neutron fluence rate around 5E+4 cm-2 s-1

2 m3 reactor grade graphite; Polyethylene shell in addition and other suitably chosen materials

Thermal fluence homogeneity should be guaranteed within few percent (the design of suitable flattening filters are also considered)

At present we are doing parametric Monte Carlo estimations to optimise shape, material thickness, source distribution in order to maximise the thermal flux density inside the column. The spatial uniformity is also an important constraint.

High purity reactor grade graphite



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High purity reactor grade graphite

Advanced routine to describe accurately the contemporary neutron emission from 6 (12) cylindrical sources with ISO AmBe lethargic energy spectrum. The emission spatial anisotropy has been taken into account, as well as an accurate description of the X3 capsule has been introduced in the model

Other ongoing research activities…

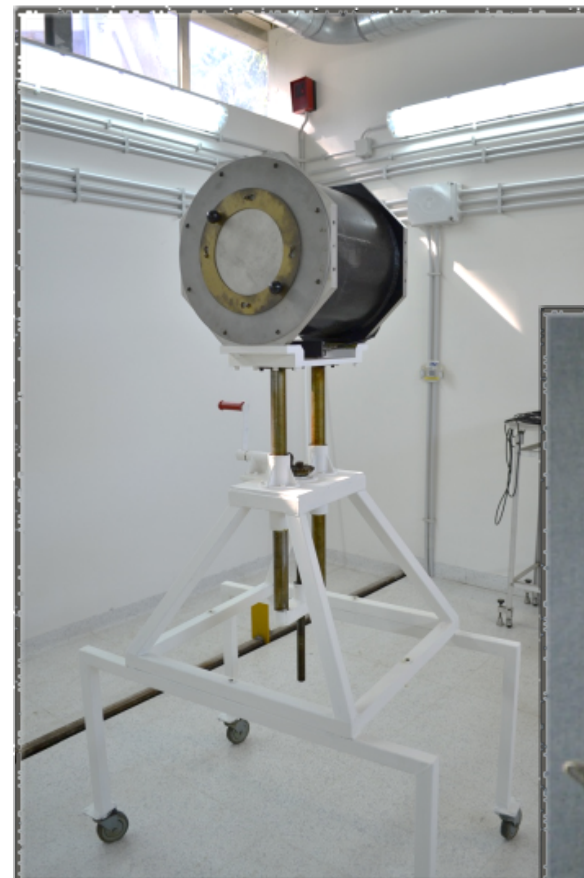
- **EMPIR SRT: Metrology for accuracy of dose to patients in hadron therapy.** Our task consists on neutron dose simulations with the major neutron transport Monte Carlo codes, for benchmarking purposes.

- **H2020, Call "SPACE" 2015, project MONSTRE Consortium, EU.** This concerns the estimation of the dose released to cells in microgravity conditions, by 14 MeV neutrons. Final goal, related to Neutron Metrology: to characterise from the metrological point of view the 14 MeV portable neutron source to be used as reference filed for calibration purpose (in the frame of an ongoing agreement between METR and UTFIS ENEA department)

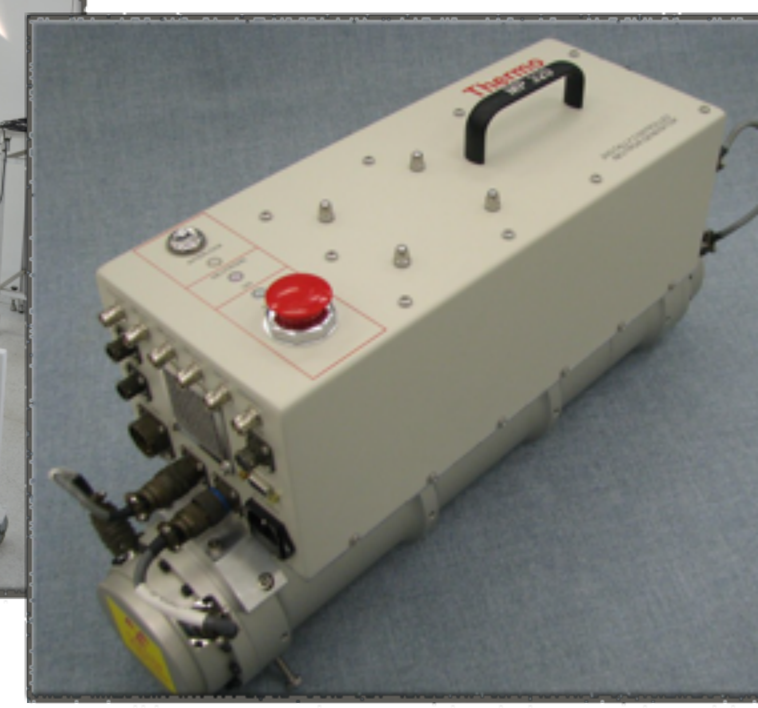
- **Put in operation the long counters ("De Pangher") as a transfer standard for neutron fluence measurements.** This will require, beside experimental work, also Monte Carlo simulations to estimate the response functions and the effective center of the detector. To this aim, it could be useful to refer to other "similar" De Pangher Long counters both in the early characterisation phase and in the final fluence measurement comparisons

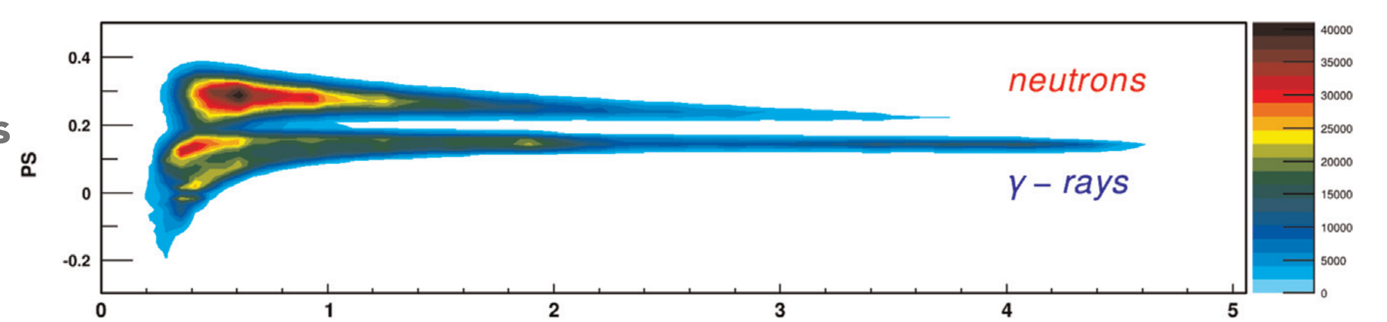
- **INFN- LNF collaboration on various experimental activities (measurement of neutron and photon spectra in reference field) and MC simulations activities (accelerator dump optimisation).**

Long Counter De Pangher



Neutron generators (NG) by (DT) at 14 MeV





Contour plot of Pulse Shape versus time-of-flight (ToF).

Neutron and gamma spectrum measurements of reference fields

In collaboration with LNF-INFN (G.Giordano, M. Iannarelli, E. Turri) and UTFUS (B.Esposito), we are designing a measurement campaign to obtain an accurate (as much as possible) reconstruction of the actual neutron spectrum from the reference 241Am/9Be source. The technique foreseen to be used is a time-of-flight, tagging fast neutrons with γ

- TheAm/Be free-neutron distribution has a maximum value of about 11 MeV and a sub-structure of peaks whose energies and relative intensities vary depending upon the properties of the Am/Be source containment capsule and the size of the 241AmO2 and Be particles in the powders employed.The average fast-neutron energy is ~4.5 MeV.

- Almost 60% of the neutrons emitted by an Am/Be source are accompanied by a prompt, time-correlated 4.44 MeV γ-ray. We exploit this property of the source to determine neutron TOF and thus kinetic energy by measuring the elapsed time between the detection of the 4.44 MeV γ-rays and the detection of the fast neutrons.

- NE-213 fast-neutron and gamma-ray detector (UTFUS) and a NaI scintillator will be used

- **In collaboration with LNF (A.Esposito) also measurements with Bonner Sphere spectrometers are foreseen**

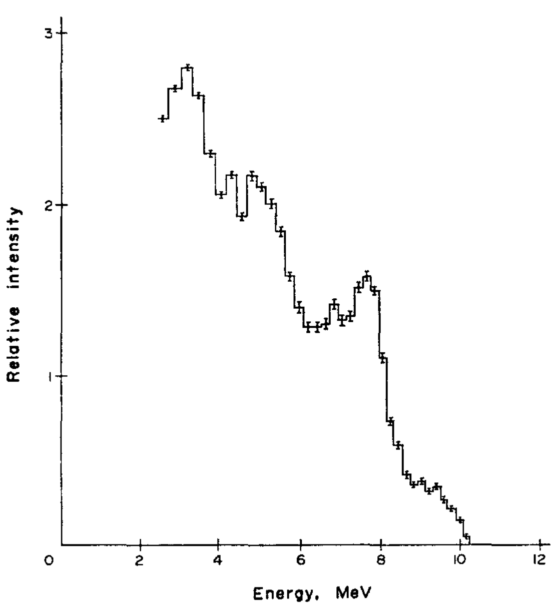


FIG. 4. ^{241}Am/Be spectrum.

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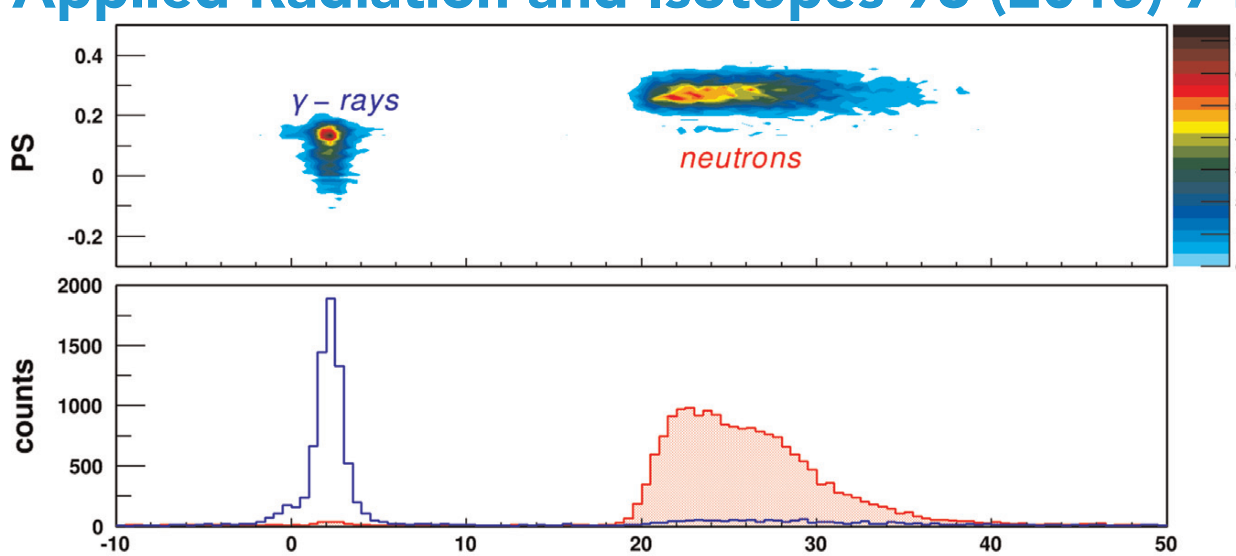
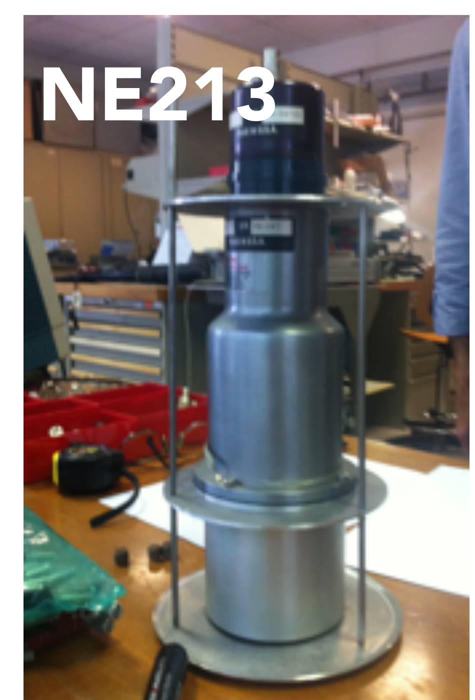


Time-of-flight distributions



web page: http://www.inmri.enea.it

ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

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EURAMET

Project T2 J06 "Brachytherapy"

Project T2 J07 "External Beam Cancer Therapy "

L'ISTITUTO

L'Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti (INMRI-ENEA) svolge attività di ricerca sui metodi di base e sui mezzi di misura delle radiazioni ionizzanti con particolare riferimento alle necessità della radioterapia, della radiodiagnostica e della radioprotezione. A tale riguardo l'Istituto svolge il ruolo assegnato all'ENEA dalla Legge 11 agosto 1991 n. 273 sul sistema metrologico nazionale.

In relazione a questo ruolo, l'Istituto deve assicurare a livello nazionale la funzione di Istituto Metrologico Primario tramite la realizzazione dei campioni nazionali e la disseminazione, mediante tarature, delle unità di misura nel settore delle radiazioni ionizzanti.

L'Istituto svolge inoltre le funzioni previste dal D. Lgs. 17 marzo 1995, n. 230 e dal D. Lgs. 27 maggio 2000, n. 241 in relazione all'obbligo di taratura e ai criteri di approvazione degli strumenti di misura delle radiazioni ionizzanti per l'esercizio della radioprotezione.

Torna su

Accessibilità

“Thank you for your attention.”